Chapter 4. Sediment Conditions

Introduction

Ocean sediment samples are collected and analyzed as part of the Point Loma Ocean Outfall (PLOO) monitoring program to characterize the general sediment quality in the region and to assess the potential impacts of wastewater discharge to the marine benthos. Analysis of parameters such as sediment particle size, sorting coefficients, and the relative percentages of coarse (e.g., gravel and sand) and fine (e.g., silt and clay) fractions provide useful information about current velocity, wave action, and overall habitat stability. Additionally, particle size composition can often be used to explain concentrations of chemical constituents within sediments since levels of organic compounds and trace metals generally rise with increasing amounts of fine particles (Emery 1960, Eganhouse and Venkatesan 1993). Finally, physical and chemical sediment characteristics are monitored because they define the primary microhabitats for benthic invertebrates that live within or on the seafloor, and subsequently influence the distribution and presence of various species. For example, differences in sediment composition and associated levels of organic loading affect the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Also, many demersal fish species are associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Overall, understanding the differences in sediment conditions and quality over time and space is crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 6, respectively).

Both natural and anthropogenic factors affect the composition, distribution, and stability of seafloor sediments on the continental shelf. Natural factors that affect sediment conditions include geologic history, strength and direction of bottom currents, exposure to wave action, seafloor topography, inputs associated with outflows from rivers and bays, beach erosion, runoff from other terrestrial sources, bioturbation by fish and benthic invertebrates, and decomposition of calcareous organisms (Emery 1960). These processes affect the size and distribution of sediment types, and also sediment chemical composition. For example, erosion from coastal cliffs and shores, and flushing of terrestrial sediment and debris from bays, rivers, and streams augment the overall organic content and grain size of coastal sediments. These inputs can also contribute to the deposition and accumulation of trace metals or other contaminants to the sea floor. Primary productivity by marine phytoplankton and decomposition of marine and terrestrial organisms are also major sources of organic loading to coastal shelf sediments (Mann 1982, Parsons et al. 1990).

Municipal wastewater outfalls are one of many anthropogenic factors that can directly influence the composition and distribution of sediments through the discharge of treated effluent and the subsequent deposition of a wide variety of organic and inorganic compounds. Some of the most commonly detected contaminants discharged via ocean outfalls are trace metals, pesticides, and various organic compounds such as organic carbon, nitrogen, and sulfides (Anderson et al. 1993). In particular, organic enrichment by wastewater outfalls is of concern because it may impair habitat quality for benthic marine organisms and thus disrupt ecological processes. For example, sulfides, which are the byproducts of the anaerobic breakdown of organic matter, can be toxic to some benthic species if the sediments become excessively enriched (Gray 1981). Additionally, nitrogen enrichment can lead to sudden phytoplankton blooms in coastal waters, resulting in further organic loading (see above). Other contaminants originating from anthropogenic sources, such as trace metals and pesticides, may become incorporated into the tissues of organisms living near or within these marine sediments, and accumulate within the food web (see Chapter 7). Lastly, the physical presence of a large outfall pipe and associated ballast materials (e.g., rock, sand) may alter the hydrodynamic regime in surrounding areas, thus affecting sediment movement and transport, and the resident biological communities.

This chapter presents analyses and summaries of sediment particle size and chemistry data collected during 2010 at monitoring sites surrounding the PLOO. The primary goals of this chapter are to: (1) characterize the spatial and temporal variability of sediment parameters in order to assess possible effects of wastewater discharge on benthic habitats, (2) determine the presence or absence of sediment or contaminant deposition near the discharge site, and (3) evaluate overall sediment quality in the region.

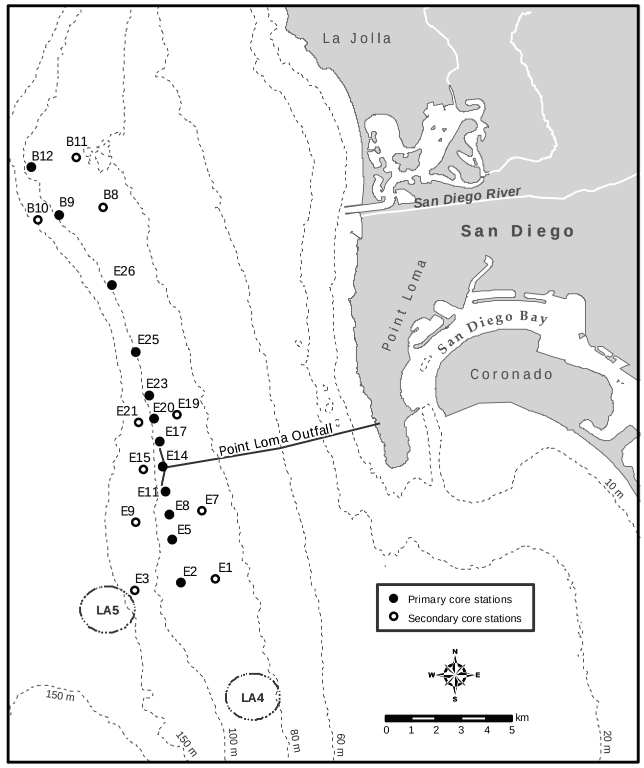

Figure 4.1
Benthic station locations sampled for the Point Loma Ocean Outfall Monitoring Program.

Materials and Methods

Field Sampling

Sediment samples were collected at 22 benthic stations in the PLOO region during January and July 2010 (Figure 4.1). These stations are located along the 88, 98, and 116-m depth contours, and include "E" stations located within 8 km of the outfall, and "B" stations located greater than 10 km from the outfall. The four stations considered to represent "nearfield" conditions herein (i.e., E11, E14, E15, E17) are located within 1000 m of the outfall wye. Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-m^2 surface area; the other grab sample from the cast was used for macrofaunal community analysis (see Chapter 5) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to standard guidelines available in USEPA (1987).

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of six nested sieves. The Horiba analyzer measures particles ranging in size from 0.00049 to 2.0 mm (i.e., 11 to -1 phi). Coarser sediments from these samples were removed prior to laser analysis by screening the samples through a 2.0 mm mesh sieve. These data were later combined with the Horiba results to obtain a complete distribution of particle sizes totaling 100%. When a sample contained substantial amounts of coarse materials (e.g., coarse sand, gravel, shell hash) that would damage the Horiba analyzer and/or where the general distribution of sediment sizes would be poorly represented by laser analysis, a set of six nested sieves was instead used to separate the grain size fractions. The mesh sizes of the sieves are 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm, and separate a seventh fraction of all particles finer than 0.063 mm. In 2010, 41 samples were processed by laser analysis and 3 samples (E3 in January, B11 and E14 in July) were processed by sieve analysis. Results from the sieve analysis and output from the Horiba were categorized into phi sizes based on the Wentworth scale (Appendix C.1). These phi sizes were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see Folk 1980). Summaries of particle size parameters included overall mean particle size (mm), phi size (mean, standard deviation, skewness, kurtosis), and the proportion of coarse, sand, silt, and clay. Additionally, the proportion of fine particles (percent fines) was calculated as the sum of all silt and clay fractions for each sample.

Each sediment sample was chemically analyzed to determine concentrations of total organic carbon (TOC), total nitrogen (TN), total sulfides, biochemical oxygen demand (BOD), total volatile solids (TVS), trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis (see Appendix C.2). TOC, TN, and TVS were measured as percent weight (% wt) of the sediment sample; BOD, sulfides, and metals were measured in units of mg/kg and are expressed in this report as parts per million (ppm); pesticides and PCBs were measured in units of ng/kg and are expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and are expressed as parts per billion (ppb). Reported values were generally limited to values above the method detection limit (MDL) for each parameter. However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry. A more detailed description of the analytical protocols is provided by the Wastewater Chemical Services Laboratory (City of San Diego 2011).

Data Analyses

Data summaries for the various sediment parameters measured during 2010 included detection rates, annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values during the year. Total chlordane, total DDT (tDDT), total PCB (tPCB), and total PAH (tPAH) were calculated for each sample as the sum of all constituents with reported values (see Appendix C.3 for individual constituent values). Statistical analyses included Spearman rank correlation of percent fines with each chemical parameter. This non-parametric analysis accommodates non-detects (i.e., analyte concentrations measured below the MDL) without the use of value substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (Conover 1980). Therefore, a criterion of <50% non-detects was used to screen eligible constituents for this analysis. In addition, only parameters analyzed with a single MDL throughout the entire year were considered for correlation analysis (Helsel 2005). Correlation results were confirmed visually by graphical analyses.

Data from the 2010 surveys were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available to assess contamination levels. The National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA) originally established the ERLs and ERMs to provide a means for interpreting environmental monitoring data. The ERLs represent chemical concentrations below which adverse biological effects are rarely observed. Values above the ERL but below the ERM represent values at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998). Contamination levels were further evaluated by comparing results for the current year with historical data, including comparisons between the maximum values for 2010 to those from the pre-discharge period (i.e., 1991–1993).

Results

Particle Size Distribution

During 2010, ocean sediments collected off Point Loma were composed predominantly of coarse

Table 4.1
Summary of particle size and sediment chemistry parameters at PLOO benthic stations during 2010. Data include the detection rate (DR), areal mean of detected values, and minimum, median, and maximum values for the entire survey area. The maximum value from the pre-discharge period (1991–1993) is also presented. ERL = Effects Range Low threshold; ERM = Effects Range Median threshold; SD = standard deviation.

	2010 Summary*					Pre-discharge		
Parameter	DR (%)	Areal Mean	Min	Median	Max	Max	ERL	ERM
Particle Size								
Mean (mm)	**	0.075	0.040	0.062	0.517	0.125	na	na
Mean (phi)	**	3.96	0.95	4.02	4.65	5.80	na	na
SD (phi)	**	1.57	1.34	1.51	2.41	3.00	na	na
Coarse (%)	**	2.3	0.0	0.0	52.9	26.4	na	na
Sand (%)	**	59.7	29.4	59.5	70.5	79.0	na	na
Fines (%)	**	38.0	15.9	38.5	58.3	74.2	na	na
Organic Indicators								
BOD (% weight)	100	346	156	335	980	656	na	na
Sulfides (ppm)	100	4.54	0.42	2.84	18.40	20.00	na	na
TN (% weight)	100	0.059	0.036	0.056	0.098	0.074	na	na
TOC (% weight)	100	0.900	0.360	0.646	4.810	1.24	na	na
TVS (% weight)	100	2.4	1.3	2.3	4.3	4.0	na	na
Trace Metals (*ppm*)								
Aluminum	100	7910	3450	7580	15,200	na	na	na
Antimony	41	0.47	nd	nd	1.20	6.0	na	na
Arsenic	100	2.92	0.78	2.71	6.11	5.56	8.2	70
Barium	100	40.30	15.30	37.00	69.40	na	na	na
Beryllium	48	0.16	nd	nd	0.33	2.01	na	na
Cadmium	93	0.15	nd	0.15	0.28	6.1	1.2	9.6
Chromium	100	17.2	7.0	15.5	32.9	43.6	81	370
Copper	100	8.78	3.75	8.19	16.30	34.0	34	270
Iron	100	12,140	4840	11,400	22,100	26,200	na	na
Lead	100	5.20	1.85	4.38	13.30	18.0	46.7	218
Manganese	100	87.9	37.6	82.5	152.0	na	na	na
Mercury	100	0.027	0.015	0.025	0.054	0.096	0.15	0.71
Nickel	100	7.16	3.30	6.96	10.60	14.0	20.9	51.6
Selenium	18	0.461	nd	nd	0.770	0.90	na	na
Silver	9	0.22	nd	nd	0.57	4.00	1	3.7
Thallium	0	—	nd	nd	nd	113.0	na	na
Tin	100	1.0	0.6	1.0	1.8	na	na	na
Zinc	100	30.5	13.3	29.6	45.3	67.0	150	410
Pesticides (*ppt*)								
HCH - Beta isomer	2	980	nd	nd	980	nd	na	na
HCB	14	159	nd	nd	220	nd	na	na
tDDT	93	640	nd	255	12,290	13,200	1580	46,100
Total PCB (*ppt*)	30	1676	nd	nd	7070	na	na	na
Total PAH (*ppb*)	11	100.1	nd	nd	294.4	199	4022	44,792

na = not available; nd = not detected

* Minimum, median, and maximum values were calculated based on all samples ($n = 44$), whereas means were calculated on detected values only ($n \leq 44$).

** Particle size parameters calculated for all samples.

silt and sands, with mean particle sizes ranging from about 0.04 to 0.52 mm (Table 4.1). Overall, the fine fraction (i.e., silt and clay) averaged 38% during the year, ranging from a low of ~16% to a high of 58% (Figure 4.2). No major changes in percent fines composition of PLOO sediments have occurred since the initiation of wastewater discharge at the end of 1993 (Figure 4.3), with the exception of a slight decrease in fines and increase in mean particle size at nearfield station E14 (see City of San Diego 2007), a station that tends to demonstrate high particle size composition variability. For example, the percent fines fraction at E14 differed by more than 14% between the January and July 2010 surveys (Appendix C.4, Appendix C.5). Other examples of relatively large intra-station differences in particle size composition between surveys included station E3, where percent fines also differed by more than 14%, and station B11, where the coarse fraction increased from ~2% in January to ~26% in July.

The sorting coefficient is calculated as the standard deviation (SD) in phi size units for each sample, therefore reflecting the range of particle sizes present, and is considered indicative of the level of disturbance (e.g., fluctuating or variable currents and sediment deposition) in an area. Most stations sampled in the Point Loma region during 2010, including stations near the outfall, had poorly sorted sediments (i.e., sorting coefficients ranging from 1.3 to 1.9; Appendix C.4). The only exceptions to this pattern occurred at stations B11 and E14 in July, where sediments were very poorly sorted (SD = 2.4 and 2.1, respectively). These high sorting coefficients may be indicative of currents or sediment deposition that is more variable than at other PLOO stations. For example, visual observations of the sediments collected at E14 in July indicated relatively high amounts of coarse black sand and gravel, possibly related to ballast and bedding material deposited during the construction of the outfall in the early 1990s.

Indicators of Organic Loading

The distribution of organic indicators (i.e., TOC, TN, TVS, BOD, sulfides) in the region during

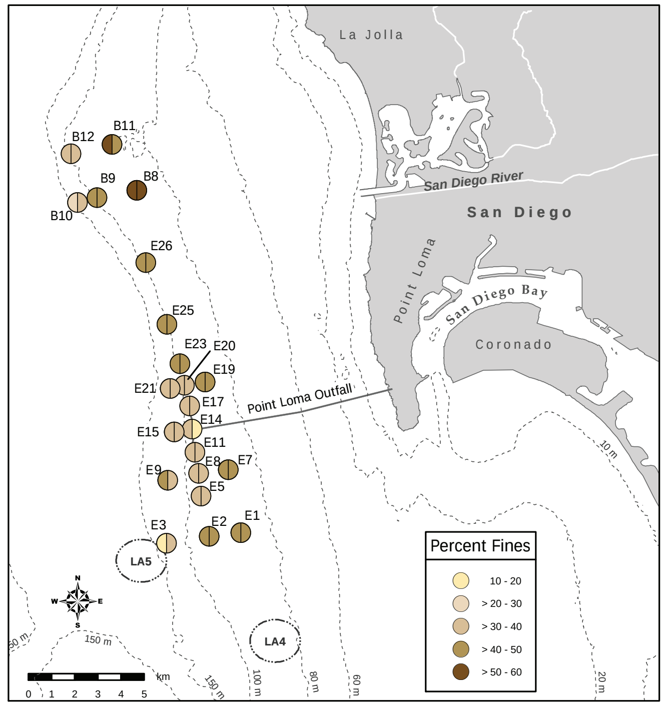

Figure 4.2
Distribution of fine sediments (percent fines) at PLOO benthic stations sampled during 2010. Split circles show results of January (left) and July (right) surveys.

2010 was generally similar to that seen prior to wastewater discharge (Figure 4.3; see also City of San Diego 1995). Each of these indicators was detected in 100% of the samples, and all but sulfides were detected at concentrations higher than the maximum values reported pre-discharge (Table 4.1). The highest concentrations of most organic indicators tended to occur at the northern “B” stations, located 10 km or more north of the outfall (Appendix C.6). The main exceptions to this pattern were values for sulfides, which were highest at station E17 in January, and BOD, which was highest at station E11 in July. In general, only sulfides, and to a lesser extent BOD, have shown changes near the outfall that appear to be associated with organic enrichment (City of San Diego 2007). Lastly, there was no correlation between sediment concentrations of organic indicators with the proportion of fine material within a sample (i.e., $r_s(44) < 0.7$).

Trace Metals

Detectable levels of aluminum, arsenic, barium, chromium, copper, iron, lead, manganese,

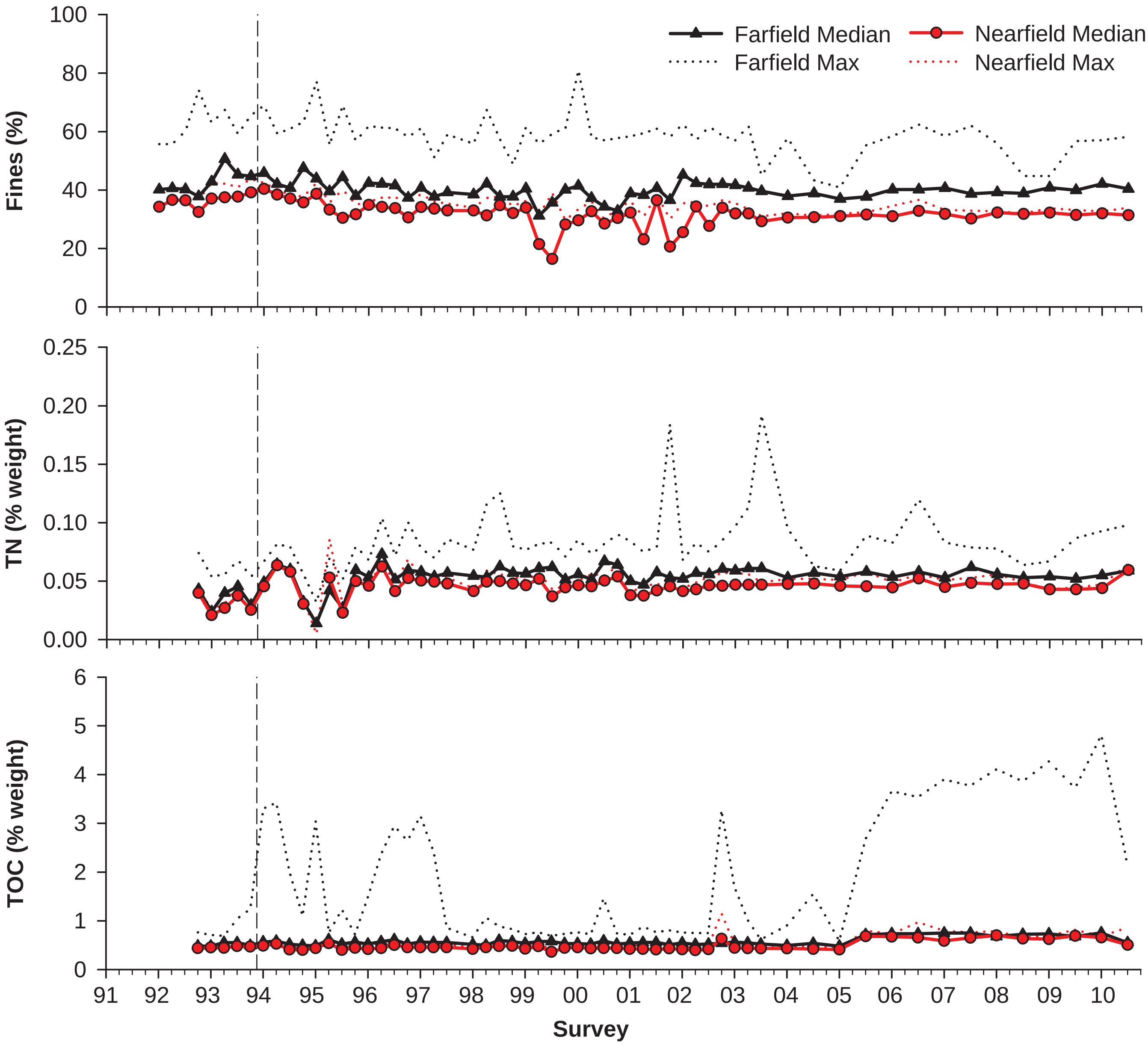

Figure 4.3
Percent fines (Fines) and organic indicator data from PLOO benthic stations sampled between 1991 and 2010. Data are expressed as median and maximum values of all farfield ($n=18$) and nearfield ($n=4$) samples during each survey; quarterly surveys were reduced to biannual (i.e., first and third quarters) in 2003; sampling was limited to primary core stations (farfield $n=9$; nearfield $n=3$) during the quarters 92-2, 03-3, 04-3, 05-1, 08-3, and 09-1 due to regulatory relief to accommodate special projects. Dashed lines indicate onset of discharge from the PLOO. Breaks in data represent surveys where the median or maximum value was below detection limits, not reportable, or not analyzed.

mercury, nickel, tin, and zinc occurred in all of the sediment samples collected in the Point Loma region during 2010 (Table 4.1). Another five metals (i.e., antimony, beryllium, cadmium, selenium, silver) were detected less frequently in 9–93% of samples, while thallium was not detected at all. Overall, concentrations of the different trace metals were low throughout the region, with most values reported for 2010 being below the maximum concentrations detected prior to wastewater discharge. Further, none of the sediment samples collected during 2010 contained metals at concentrations exceeding ERL or ERM thresholds. In addition to being low overall,

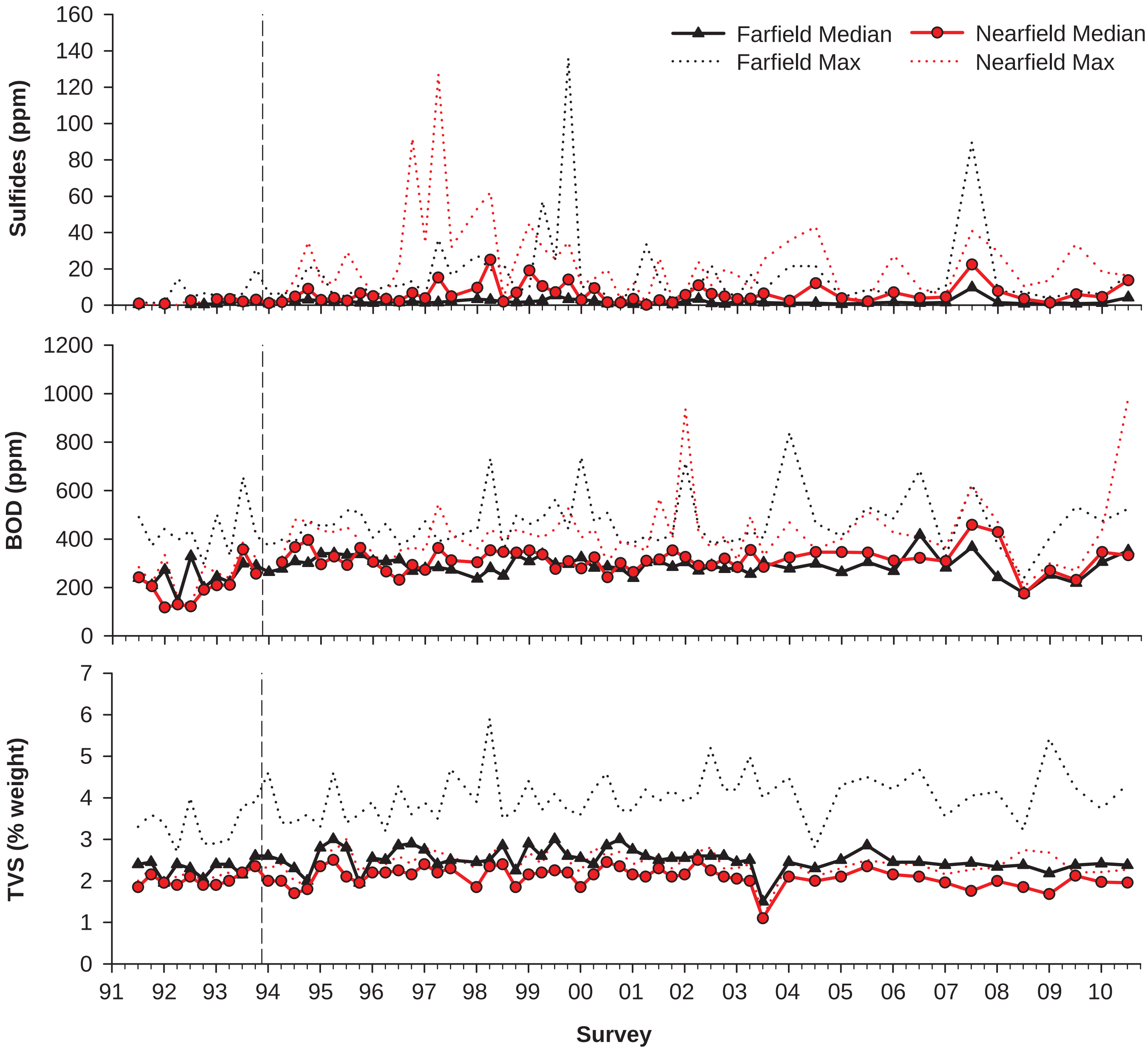

Figure 4.3 *continued*

metal concentrations were spatially variable, with no discernable patterns relative to the outfall (Appendix C.7) or with the proportion of fine material present in the sample (i.e., $r_s(44) < 0.7$). The highest concentrations of most metals occurred in sediments from the northern "B" stations, while the highest concentrations of a few others occurred at the "E" stations located south of the outfall. For example, the highest concentrations of barium and mercury were detected at stations E2 and E1 in January, respectively. In contrast, the maximum arsenic concentration detected in 2010 occurred in sediments collected at station E14 in July; this was the only instance during 2010 that a metal was found at higher concentrations than during the pre-discharge surveys.

Pesticides

Chlorinated pesticides were detected in up to 93% of the sediment samples collected from PLOO stations in 2010 (Table 4.1, Appendix C.8). Total DDT (primarily p,p-DDE) was the most prevalent pesticide, occurring at an overall mean concentration of 640 ppt. Concentrations of this pesticide exceeded the ERL (1580 ppt) in sediments from station E2 in January (1870 ppt) and B9 in July (12,290 ppt), both of which were below the maximum value of DDT reported for the region during the pre-discharge period (13,200 ppt). Another pesticide, HCB, was detected in 14% of the sediment samples at concentrations ranging from 76 to 220 ppt. HCB occurred at six sites throughout the region in January, including nearfield station E17, but was not detected in any samples in July. The maximum concentration of HCB was detected at station E5, located to the south of the outfall. A third pesticide, HCH (beta isomer), was detected at B11 in July at a concentration of 980 ppt. As with the organic indicators and most metals, no patterns indicative of an outfall effect were evident in the distribution of pesticides during 2010.

PCBs and PAHs

PCBs were detected in 30% of all PLOO sediment samples during 2010 (Table 4.1), most of which were collected from stations south of the outfall (Appendix C.8). Total PCB concentrations ranged from 53 to 7070 ppt in the region, with the maximum concentration occurring in sediment from station E21 in January. The most commonly detected PCB congeners were PCB 153/168, PCB 118, PCB 138, and PCB 149. Sediment from station E1 in January contained the most congeners (19) detected in a single sample. Overall, there was no evidence of PCB accumulation surrounding the PLOO.

PAHs also occurred infrequently in 2010, and were detected at only three sites, each located south of the outfall (i.e., stations E1, E2 and E3) (Appendix C.8). Total PAH concentrations ranged from about 20 to 294 ppb, well below the ERL of 4022 ppb (Table 4.1). The compounds 3,4 benzo(B)fluoranthene, benzo[A]anthracene, and benzo[A]pyrene occurred at all three of the above stations (Appendix C.2), while an additional five PAH compounds were also detected at station E1. Sediments collected from this station in January contained the highest tPAH concentration for the year. As with PCBs, there was no apparent relationship between PAH concentrations and proximity to the outfall discharge site.

Discussion

Ocean sediments at stations surrounding the PLOO in 2010 were composed primarily of sands and coarse silt. Most of these sediments were poorly sorted, consisting of particles of varied sizes, which suggest that sediments in the region were subject to low wave and current activity and/or variable physical disturbance (Folk 1980). The very poorly sorted samples collected at stations B11 and E14 in July were exceptions, containing substantially more gravel and very coarse sands, and less fine sands and silt than most other stations in the region. The sample from station E14 in particular consisted of over 50% coarse particles, which may have originated as ballast or bedding material for the outfall structure. Overall, variability in the particle size composition of sediments in the PLOO region is likely affected by both anthropogenic and natural influences, including outfall construction materials, offshore disposal of dredged materials, multiple geologic origins of different sediment types, and recent deposition of sediment and detrital materials (Emery 1960, City of San Diego 2007, Parnell et al. 2008). The PLOO lies within the Mission Bay littoral cell, with natural sources of sediments including outflows from Mission Bay, the San Diego River (Patsch and Griggs 2007), as well as San Diego Bay. However, fine particles may also travel in suspension across littoral cell borders up and down the coast (Farnsworth and Warrick 2007), thus widening the range of potential sediment sources to the region.

Concentrations of various contaminants, including indicators of organic loading (i.e., BOD, TOC, TN, sulfides, TVS), trace metals, chlorinated pesticides (e.g., DDT), PCBs, and PAHs in sediments off Point Loma remained within the typical range observed for San Diego and other areas of the southern California continental shelf (see Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006, Maruya and Schiff 2009). Although DDT was detected above the ERL for this pesticide at two stations, these concentrations were below the maximum value detected in the region pre-discharge.

There were no clear spatial patterns in sediment contaminants relative to the PLOO discharge site in 2010, with the exception of slightly elevated sulfide and BOD levels near the outfall as described in previous years (City of San Diego 2007). Instead, the highest concentrations of several organic indicators, metals, pesticides, PCBs, and PAHs were found in sediments from the southern- and/or northern-most farfield stations. Historically, concentrations of contaminants have been higher in sediments at southern stations (i.e., E1–E3, E5, E7–E9) than elsewhere off San Diego, which may be due in part to short dumps of dredged materials destined originally for LA-5 (Anderson et al. 1993, City of San Diego 2003, Steinberger et al. 2003, Parnell et al. 2008).

Overall, there is little evidence of contaminant loading or organic enrichment in sediments throughout the PLOO region after 17 years of wastewater discharge. For example, concentrations of most measured parameters continue to occur at levels within the range of variability typical for the San Diego region (e.g., see City of San Diego 2007). The only sustained effects have been restricted to a few sites located within about 300 m of the outfall (i.e., stations E11, E14 and E17). These effects include a minor increase in sediment particle size through time, measurable increases in sulfide concentrations, and smaller increases in BOD (City of San Diego 2007). However, the data do not suggest that wastewater discharge is affecting the quality of benthic sediments to the point that it will degrade the resident marine biota in the PLOO region (e.g., see Chapters 5 and 6).

Literature Cited

Anderson, J.W., D.J. Reish, R.B. Spies, M.E. Brady, and E.W. Segelhorst. (1993). Human Impacts. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 682–766.

City of San Diego. (1995). Outfall Extension Pre-Construction Monitoring Report (July 1991–October 1992). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2003). An Ecological Assessment of San Diego Bay: A Component of the Bight'98 Regional Survey. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Appendix E. Benthic Sediments and Organisms. In: Application for Renewal of NPDES CA0107409 and 301(h) Modified Secondary Treatment Requirements Point Loma Ocean Outfall. Volume IV, Appendices A thru F. Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2011). 2010 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Conover, W.J. (1980). Practical Nonparametric Statistics, 2ed. John Wiley & Sons, Inc., New York, NY.

Cross, J.N. and L.G. Allen. (1993). Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 459–540.

Eganhouse, R.P. and M.I. Venkatesan. (1993). Chemical Oceanography and Geochemistry. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 71–189.

Emery, K.O. (1960). The Sea off Southern California. John Wiley, New York, NY.

Farnsworth, K.L. and J.A. Warrick. (2007). Sources, dispersal, and fate of fine sediment supplied to coastal California. U.S. Geological Survey Scientific Investigations Report 2007–5254. Reston, VA.

Folk, R.L. (1980). Petrology of Sedimentary Rocks. Hemphill, Austin, TX.

Gray, J.S. (1981). The Ecology of Marine Sediments: An Introduction to the Structure and Function of Benthic Communities. Cambridge University Press, Cambridge, England.

Helsel, D.R. (2005). Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, Inc., Hoboken, NJ.

Long, E.R., D.L. MacDonald, S.L. Smith, and F.D. Calder. (1995). Incidence of adverse biological effects within ranges of chemical concentration in marine and estuarine sediments. Environmental Management, 19(1): 81–97.

Mann, K.H. (1982). The Ecology of Coastal Marine Waters: A Systems Approach. University of California Press, Berkeley, CA.

Maruya, K.A. and K. Schiff. (2009). The extent and magnitude of sediment contamination in the Southern California Bight. Geological Society of America Special Paper, 454: 399–412.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2003). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Parnell, P.E., A.K. Groce, T.D. Stebbins, and P.K. Dayton. (2008). Discriminating sources of PCB contamination in fish on the coastal shelf off San Diego, California (USA). Marine Pollution Bulletin, 56: 1992–2002.

Parsons, T.R., M. Takahashi, and B. Hargrave (1990). Biological Oceanographic Processes 3rd Edition. Pergamon Press, Oxford.

Patsch, K. and G. Griggs. (2007). Development of Sand Budgets for California's Major Littoral Cells. Institute of Marine Sciences, University of California, Santa Cruz, CA.

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: III. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Snelgrove, P.V.R. and C.A. Butman. (1994). Animal-sediment relationships revisited: cause versus effect. Oceanography and Marine Biology Annual Review, 32: 111–177.

Steinberger, A., E. Stein, and K. Schiff. (2003). Characteristics of dredged material disposal to the Southern California Bight between 1991 and 1997. In: Southern California Coastal Water Research Project Biennial Report 2001–2002. Long Beach, CA. p 50–60.

[USEPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuary Protection, Washington, DC.